SSRG International Journal of Recent Engineering Science
ISSN: 2349 – 7157 / https://doi.org/10.14445/23497157/IJRES-V9I1P106

Volume 9 Issue 1, 39-50, Jan-Feb 2022

Review Article

A Review of Biofertilizer Production: Bioreactor, Feedstocks and Kinetics

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Received: 13 January 2022 Revised: 18 February 2022 Accepted: 27 February 2022 Published: 28 February 2022

Abstract *- Synthetic fertilizers affect soil fertility when used for a long frame of time, negatively influencing human health. Biofertilizer, prevent damage to the natural origin of the soil, adds nutrient to soil and, to some degree, aid in cleaning nature from precipitated chemicals. This paper reviews the various type of biodigesters used in the production of biofertilizers, feedstocks, majorly waste from abattoirs, peels of various fruit, animal dung, human excrete and other agricultural waste. The study found that waste generated and disposed to litter the environment could be potentially harnessed for nontoxic and environmentally friendly fertilizer.*

Keywords *- Biofertilizer, Bioreactor, Solid waste, Anaerobic digestion, Microbes, Kinetics model.*

1. Introduction

Environmental conservation has become more and more important in recent times, and most importantly, the utilization of waste as a wealth commodity for both human and environmental benefit. Biofertilizers are ecologically pleasant fertilizers that save damage to natural soil origin and aid, to some degree, the cleaning of precipitated chemical fertilizers [1]. Biofertilizers add nutrient input for plant growth, which is the main organic or inorganic source. It increases microbial processes in the soil that add nutrients that plants can simply assimilate and assemble nutritive elements from non-usable forms to usable forms through biological processes [2]. Anaerobic digestion is a process that degrades organic waste in an airtight container with anaerobic microorganisms in a reactor called a bioreactor or biodigester, and the products are mainly biogas that is majorly composed of methane, carbon dioxide and digestate bio-fertilizer use as soil conditioners [2]. A bioreactor is a design vessel in which microorganisms, enzymes, plant cells or animal cells are used for converting substrates to the product through fermentation under controlled conditions [3]

The properties of biofertilizers consist of bulk density, total solid, chemical oxygen demand, and biological oxygen demand. Bulk density is calculated as a ratio between the dry weights of the sample in (g) to its volume (cm^3) [5]. It was also found to increase with the agitation speed [6]. The total solid (TS) comprises all the suspended, colloidal and dissolved solids in a sample. Total solid is measured by weighing the amount of solid present in a known volume sample [7].

Additionally, biological oxygen demand is the amount of oxygen consumed by bacteria and other microorganisms while decomposing organic matter under a specified condition of temperature and pH. Furthermore, chemical oxygen demand measures the oxygen required to oxidize soluble organic particulate [2]. The pH of the biofertilizer process indicates whether the digestion process is proceeding without disturbance; the pH should be about 7 [8]. Other significant properties of biofertilizers include moisture content, electrical conductivity, hydrogen ion concentration, total nitrogen, organic matter, phosphorus, potassium, and microbial changes [9]. The biofertilizer is a beneficial commodity to both man and the environment.

Biofertilizers fix atmospheric nitrogen in the soil to the plants [10]. On the other hand, it also solubilizes the insoluble phosphate forms, such as tricalcium, iron and aluminium phosphates, into available forms [11]. Additionally, reference [12] stated that bio-fertilizers scavenge phosphates from soil layers, [34] found that it produces hormones and anti-metabolites which promote root growth and also [13] reported that it decomposes organic matter, which helps in the mineralization of soil. When applied to the soils or seeds, bio-fertilizers increase nutrient availability and yield by 20% without any effect on the soil and the environment [13].

This paper reviews the various type of bioreactors used in the production of biofertilizers, feedstocks which are majorly waste from abattoirs, peels of various fruit, animal dung, human excrete and other agricultural waste. Also, the various biofertilizer processes, including anaerobic digestion and the kinetic models of microbial growth, are discussed.

2. Types of Biofertilizers and Method of Production

The main types of bio-fertilizers are nitrogen-fixing, phosphorus solubilization, potassium solubilization, zinc solubilization, and iron sequestration biofertilizers [12]. These biofertilizers have their impetus and part in plant growth and development. Biofertilizers improve nutrients over the normal processes of fixing atmospheric nitrogen, solubilizing phosphorus, and piquing plant growth by synthesizing growth-promoting substances [11], which can be classified in different ways grounded on their kind and function [10].

2.1. Nitrogen Fixing Bio-Fertilizer (NBF)

Nitrogen is the most vital element regulating nutrients for plants [14]. Plants can absorb nitrogen from the soil in nitrate (NO_3) and ammonium (NH_4). Hence, the atmospheric nitrogen is converted to fixed forms of nitrogen to become available to plants which are accomplished through a microbiological process called Biological Nitrogen Fixation (BNF), followed by a process known as nitrification [10]. An excessive amount of azotobacter in cultivated soils and the rhizosphere of plants is low due to deficiency of organic matter in the soil, or the wind washes away the nitrogen. Therefore, applying nitrogen-fixers biofertilizers will improve the presence of nitrogen-fixing bacteria [15].

2.2. Phosphorus-Solubilizing Bio-Fertilizer (PSB)

Phosphorus is among the vital macronutrient that plays a key role in the growth and development of the plant. It is found in the soil between 400–and 1200 mg/kg [14]. It is present in two forms in soil, i.e. inorganic and organic [16]. Reference [14] stated that phosphorus is abundant in soil (0.05%) in organic and inorganic forms. Still, only 0.1% is available. The main reason for the non-availability of soil phosphorus is its presence as insoluble salts in the soil, which is about 95%-99% of the total soil phosphorus.

Plants can only use phosphate as $H_2PO_4^-$ or HPO_4^- [17]. Microorganisms such as rhizobacteria can solubilize the insoluble complex inorganic phosphates to accessible phosphate ions. Such procedures are being carried out by the low molecular weight organic acids synthesized due to microbial sugar metabolism. They can act as chelators of divalent cations ensuing the solubilization of insoluble phosphates [18].

Phosphorus-solubilizing bacteria in the soil, such as *Pseudomonas* and *Bacillus* and fungi, such as *Aspergillus* and *Penicillium*, solubilize phosphate and fixed phosphorus to make it accessible for plants. 20–25% phosphorus requirement of plants is content by PSB [12]. Due to its immobile nature, phosphorus is deficient in tropical and subtropical soils. It helps convert food energy into chemical energy during photosynthesis and into chemical energy to be removed during respiration [4].

Phosphorus solubilizing bio-fertilizer application is used to aid remedy and make phosphorus more bioavailable and bio-accessible for plant growth and development [17]. For example, reference [4] stated that phospho-bacterin aids in solubilizing insoluble phosphate, making it more available to plants.

2.3. Potassium Solubilization (K)

Potassium is the third most vital element for plant growth [13]. It also plays a role in photosynthesis and sugar degradation [4]. This macronutrient is presented in the soil as mineral potassium, non-exchangeable potassium, and exchangeable potassium. The total amount of K in the soil is 0.04% to 3% [17]. However, most of the soil potassium is mineral K. Therefore, it becomes directly inaccessible to plants [17]

Various groups of microorganisms, such as bacteria and fungi, increase potassium availability due to producing a number of organic acids [11]. However, reference [19] found that the mechanisms of intricate K solubilization contain changing unavailable K into available form by *Bacillus mucilaginosus* and *Bacillus edaphicus*.

2.4. Benefits of using Biofertilizer

Previously, [10] stated the merit of using biofertilizers is that it increases harvest yields, ameliorate the way individual particles of sand, silt, and clay are assembled, reduction in production costs, provisions protection against drought and some soil-borne diseases, suppresses the incidence of insect pests and plant diseases. Bio-fertilizers also have live or dormant cells of well-ordered strains of phosphate solubilizing, nitrogen-fixing, or microorganisms capable of secreting enzymes depending on the hydrolysis of lignocellulose used for the application to seeds, soil or composting areas [20]. Also, [21] report that biofertilizer quickens some microbial processes in the soil, which add the amount of availability of nutrients in a form simply taken by plants and also assembling nutritive elements to functioning form over biological processes cellulolytic microorganisms used for the application to seeds, soil or composting areas.

Bio-fertilizers also safeguard the plants from saltiness, prolong periods of abnormal rainfall stress and are economically effective [22]. Additionally, bio-fertilizer is environmentally pleasant, contaminants free, and cost-effective. It also increases the yield of crops up to 10-40% and fixes nitrogen up to 40-50 Kg. After perpetual usage for 3-4 years, there is no need for bio-fertilizers, as parental inoculums are enough for growth and multiplication [23].

2.5. Feedstock for Bio-Fertilizers Production

Most Bio-fertilizer feedstocks are produced from biological and agro-waste, which include: abattoir waste, pineapple peel, watermelon peel, Brewer's spent grain, banana peel, orange peel, paper coconut water waste of the porridge manufacturer, and palm oil mill effluent [24, 26]. [26] Found that Brewer's spent grain and palm oil mill effluent, with the addition of compost, improved bio-fertilizer properties. [27] Discovered that coconut wastewater from porridge manufacturers with more microbial groups living symbiotically can be used as the potential feedstock and culture source for the production of liquid bio-fertilizer. Moreover, [28] reported that bio-fertilizers prepared from cyanobacteria are economical and ecologically friendly. The literature [29] reported that acetobacter could be used to produce bio-fertilizer. Reference [30] revealed that organic compost and bio-fertilizer combination improved productivity. Additionally, [31] discovered that watermelon peel and cow dung in a ratio of 1:1 was effective for producing bio-fertilizer with a yield of 83.35%. Furthermore, [24] reported that muck streams from abattoirs have much perspective for investment in anaerobic digestion and bond together the wastes generated in Nigerian abattoirs for biogas and bio-fertilizer production.

In their work, [14] found that poultry bones and ashes phosphorus can be reused via microbiological solubilization and used as a biofertilizer. Also, reference [32] stated that bio-fertilizer can be produced from cow, chicken dung, and sheep dung (Animal waste). Furthermore, [13] reported that bio-fertilizer produced from watermelon peel, pineapple peel and banana has a high pH value and less potassium content. While the combination of watermelon peel, banana peel and pineapple has a high potassium value, meaning that the presence of banana peel increases potassium content. Similarly, [36] reported that the mixed combination of banana peel, orange peel, paper, pineapple peel and watermelon peel gave the best result of 17.21% N, 10.24% P, 48.32% K and a C/N ratio of 29 in comparison with the other mixture of watermelon peel, banana peel. Also, [33] reported the potential of groundnut shells for biofertilizer production.

[34] discovered that producing bio-fertilizer of different solid wastes has high usefulness, strength, cost-effectiveness, straightforward application, and multi-functionality of biofertilizers increases. Reference [1] also discovered that sawdust, kaolin, vermiculite, diatoms, and wheat bran could produce better bio-fertilizers. [35]. It is reported that using cultivated wastes, co-products, and by-products is likely to reuse mostly inorganic agriculture wastes into bio-fertilizer.

Due to the financial limitations and little or no reinforcement, developing countries lack sufficient ability to handle wastewater sludge resulting in serious environmental pollution [36]. Wastewater sludge contains organic compounds, nutrients, and pathogens, which can be used to produce renewable energy, stabilized soil conditioners, and fertilizers for agricultural purposes [36]. In the anaerobic digestion of sludge, the organics, minerals, and most nutrients are removed; 100% phosphorus and 50 to 70% nitrogen as ammonia remain in the sludge [37].

In the work of [38]. Earthworm *Eudrilus eugeniae* was used in the vermicomposting process to produce biofertilizer, a mixture of wastewater sludge, cow dung and cassava waste. The nitrogen, phosphorus, and potassium concentration increased by 50, 24 and 10%. While [39] reported that the composting method in which the combination of sewage sludge, sawdust, urine, and cow dung at different ratios of 2:1, 4:1, 6:1 and 8:1the result shows that the mixture of sawdust and sewage at a ratio of 6:1 has higher nitrogen concentration in comparison to the other ratio.

Banana peels contain macronutrients, which are essential elements needed by plants, including nitrogen, phosphorus, potassium, Calcium, sulphur, and Magnesium [40]. Compare biofertilizers produced from banana peel and orange to commercial organic fertilizers. The fertilizer produced by composting banana peel has less difference from the organic Nile compost fertilizer. Additionally, [41] used banana peel as a fermentation liquid in biofertilizer production from food waste. The NPK is as follows: Nitrogen is 35325 mg/L to 78775 mg/L, phosphorus 195.83 mg/L to 471 mg/L, and potassium is 422.3 mg/L to 2046 mg/L. The result obtained was compared with some organic compost in the market with minor differences.

The routine use of chicken dung on the soil as an organic fertilizer is the cheapest and most environmentally safe method of discarding the volume produced by the fast-growing poultry industry [42, 43]. However, little is known about the safety of chicken litter for soil application and wide-ranging release into the environment. For instance, fresh poultry compost has high salinity, affecting crop yields, as vegetables (especially carrots) are highly affected because of their high sensitivity to salinity [44]. Chicken dung is an exceptional soil transformer that provides nutrients for growing crops and improves soil fertility when applied wisely [45]. Chicken dung is one of the greatest organic manure with much content of macronutrients such as nitrogen, phosphorus and potassium [46]. Table 2 shows several authors' recent work on various feedstocks for biofertilizer production.

2.6. Method of Biofertilizer Production

In the literature, there are several methods adopted for the production of bio-fertilizer, including vermicomposting method (a process involving various species of worms, especially red wigglers, white worms. etc.) [48], fermentation method [13], biotechnological process [8], aerobic co-composting/re-composting processes [35], closed system cultivation using sunlight [28] and anaerobic digestion [26]. Furthermore, [48] reports vermicomposting system materials mainly consist of flasks, crusher, water, solid waste, *Eudriluseugeniae* (African worm), thermometer, pH scale and sieve. At the same time, the feedstocks include the banana peel, orange peel, paper, pineapple peel and watermelon peel with a combined result of 17.21% N, 10.24% P, and 48.32% K, which does not suit any appropriate NPK ratio.

Additionally, the aerobic co-composting/re-composting process was reported by [35]; their findings indicate that it is likely to reuse principally in-organic agriculture wastes and can be used as a bio-fertilizer. [25] Report that fermentation method using the watermelon peel and pineapple and found that the bio-fertilizer produced has a pH value of 5.15 and less potassium content. Using a biotechnological process, [49] reported poultry bones and ashes as feedstocks for the production of phosphorus bio-fertilizer; they demonstrated that it is possible to reuse the existing phosphorus present in bones via microbiological solubilization and can be used as a fertilizer.

Table 2. Recent studies on bio-fertilizer feedstock

Reference	Feedstock	Major Findings
[47]	Microalgae biomass (MB)	Microalgae bio-fertilizer had a higher ecological influence than triple superphosphate (TSP).
[27]	Coconut water waste of the porridge manufacturer, consortium microbes	Coconut wastewater with molasses and normal microbes can be used as the prospective material and culture medium for producing liquid biofertilizers.
[26]	Brewer’s spent grain, palm oil mill effluent.	Results indicated compost addition to the feedstock boosts the bio-fertilizing properties.
[24]	Waste streams from abattoirs	Waste generated from the abattoir is promising for Biofertilizer production via anaerobic digestion.
[34]	Solid waste of different types (bagasse, paper pulp, wheat bran, rice and rice straw, vegetable and fruit waste, and synthetic media)	Usefulness, equilibrium, cost-effectiveness, ease in Application and multi-functionality bio-fertilizers.
[2]	Cow dung and watermelon peel	Biofertilizer with a yield of 83.35% (N: 25 mg/L; P_2O_5: 5.2 mg/L and K_2O: 4.8 mg/ L)...
[48]	Banana peel, orange peel, paper, pineapple peel, watermelon peel	The (mixed combination) gave the result of 17.21% N, 10.24% P, 48.32% K and a C/N ratio of 29.
[13]	Watermelon peel and pineapple	The biofertilizer is acidic and has less potassium content.

[26] Conducted the anaerobic digestion technique in the laboratory with Amber borosilicate glass serum bottles, 20 mm aluminium crimp seal and reactors. They used Brewer's spent grain palm oil mill effluent as feedstocks; the results indicated that manure addition enhanced the bio-fertilizing properties produced from Brewer's spent grain palm oil mill effluent. According to the study [2], biofertilizer production from cow dung and watermelon peel as feedstock can yield up to 83.35%. The biochemical reaction involved in the biofertilizer production process is presented in Equation 1 [2].

$$\text{Substrate} \rightarrow CH_4 + CO_2 + H_2 + NH_3 + \text{Bio-fertilizer} \qquad (1)$$

Anaerobic digestion is a sequence of bio-metabolism stages (biochemical mechanism of anaerobic digestion), including hydrolysis, acidogenesis, acetogenesis, and methanogenesis. [8,49]. According to [51], the first step in hydrolysis is the breaking down of higher molecular weight organic matter such as lipids, carbohydrates, and protein into smaller soluble organic matter like fatty acid, glucose, and amino acid by the presence of exo-enzymes. In contrast, the second stage is known as acidogenesis, and the hydrolytic process transforms the products into volatile fatty acids by the action of the acidogenic bacteria. For the third stage, which is acetogenesis, in this stage, the bacteria are reduced to produce acetates CHCOO- and hydrogen [51]. Finally, the last stage, methanogens, plays a vital role in producing methane gas by bacteria (methanogens). They ingest acetic acid or H_2 as the obtainable substrates in their regular environment to produce methane.

Digestion types are notably based on the temperature in the digester. These include psychrophilic digestion (10-20 °C, retention time over 100 days), mesophilic digestion (20-35 °C, retention time over 20-40 days), thermophilic digestion (50-60 °C, retention time over 8 days) [2,32]. The pH of the fermentation slurry specifies whether the digestion process is proceeding without disturbance; the pH should be about 7 [34].

2.7. Safety in Biofertilizer Production

According to [26], it is necessary to take safety measures when dealing with bio-fertilizer comprising correct handling of bio-fertilizer since they are living organisms, usage of bio-fertilizer before the expiry date should not be exposed to direct sunlight since they are species-specific hence, particular bio-fertilizer should be used for a particular crop plant and applied based on the recommended dose. European Union regulatory framework state that only certain microorganisms can be used as bio-stimulants (*such as Azotobacter spp., Mycorrhizal fungi*, *Rhizobium spp. and Azospirillum spp*) and does not promise the safety of the strains accepted to be registered as safe, since it is grounded on a taxonomic condition [74]. For instance, legumes require 0:1:1 for the NPK ratio, while for vegetables, the NPK ratio is 6:24:24, and cereal crops require a 20:10:10 NPK ratio [75]. The time taken for the shelve life of biofertilizer could be around 6 months, while for liquid biofertilizer is as high as two years [76].

As a safety measure, at all times after working around the bio-digester, the surrounding must be washed deeply. Although Pathogens are destroyed by heat, there might still be pathogens in the digested slurry. Therefore, it is advisable to reuse the effluent by mixing it with fresh feedstock and then pouring back into the digester. Alternatively, add the slurry to a compost heap, where the heat will destroy any remaining pathogens [8].

3. Bioreactors and Biodigesters

3.1. Bioreactor

The bioreactor is a receptacle, container or vessel in which microorganisms, enzymes, plant cells or Animal cells are used for changing substrates to the product via fermentation under controlled conditions that are right for the fermentation process [3]. While biodigester utilizes organic waste, animals and humans excrete it to produce biofertilizer and biogas [52]. Biodigesters are mainly used for the digestion process only. In contrast, on the other hand, bioreactors are applicable in pharmaceuticals for the production of antibiotics, cell growth, enzyme production, protein synthesis and milk processing [52]. In a no-shell, both bioreactors and biodigesters convert substrate into product. Bioreactor increases the decomposition of waste [53] where liquids such as wastewater and wastewater treatment plant sludge are desired to rise the natural biodegradation process [54].

Recently, there has been a rise in demand for many biological enzymes, industrial chemicals, biofuel, food, phenolic, feed, and pharmaceutical products [55]. Hence, there is an equivalent rise in demand for bioreactors for waste management technology applications, including bioremediation, detoxification, bioleaching and bio-pulping [56]. In a bioreactor, a microbiological decay of organic matter occurs in the absence of oxygen common to many natural environments to produce biogas and digestate (biofertilizer) in airtight reactors known as digesters and by the action of a broad range of microorganisms [7]. There are numerous types of bioreactors: batch, stirred, fluidized-bed and bubble Column bioreactors [57].

3.1.1. Batch Bioreactor

A classic batch bioreactor is made of a tank with a stirrer and a heating or cooling system. These containers may be different in shape and size, typically made up of steel, glass or alloy, and the feedstocks are fed through connections in the top cover of the reactor [57]. Gases also are discharged through the top of the container, while on the other hand, liquids are commonly discharged from the bottom. In a batch bioreactor, the culture broth is charged into the reactor at the start of the process [52]. Figure 1 shows a typical batch bioreactor.

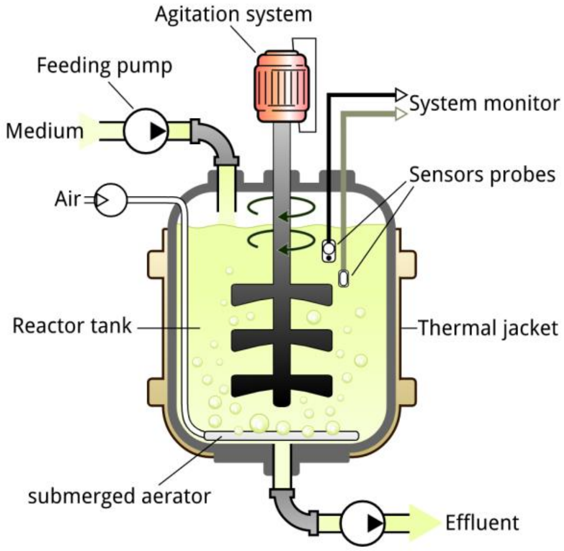

Fig. 1 A typical batch bioreactor microbial cultivation process [58]**.**

3.1.2. Stirred Tank Bioreactor

The continuous stirred tank bioreactor is made up of a cylinder-shaped container with a motor shaft that aids in one or more agitators (impellers); the shaft is attached to the bottom of the bioreactor [57]. Figure 2 shows a typical stirred tank reactor.

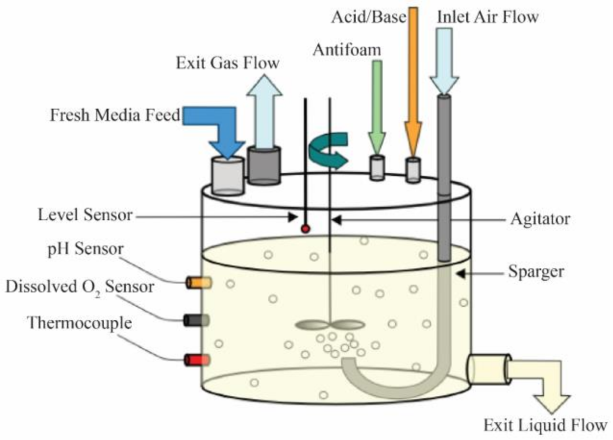

Fig. 2 A typical stirred tank reactor [57]

Furthermore, the contents do not vary with time in a continuous stirred tank bioreactor (CSTR). This simply means that in a steady-state system, which applies to the hold up of microorganisms and the concentration of the components of the medium in the fermenter, and also stirred tank reactor, perfect mixing is achieved [59].

The two forms of continuous stirred tank reactor based on operation mode are chemo-stat used for cell culture in which all nutrients are added in excess, and the liquid volume is kept constant by setting the inlet and outlet flow rates equal [60]. While the in the turbidostatic, cell concentration is maintained constant by observing the culture's optical density and the liquid volume is kept constant by setting the outlet flow rate equal to the inlet flow rate [57]. The continued stirred tank reactor is used in wastewater treatment and production of primary metabolites, lactic acid and methanol [61].

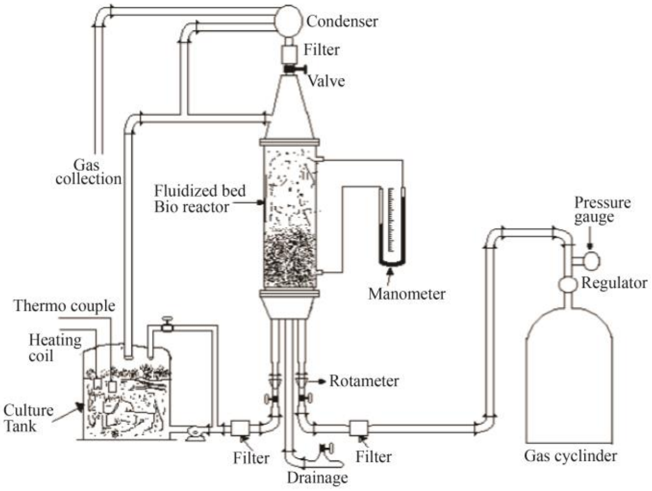

Fig. 3 A setup of fluidized bed bioreactor [61]

3.1.3. Fluidized-bed Bioreactor

A porous plate brands a fluidized bed reactor and a distributor which supports the catalytic material, and the fluid is forced up through the solid material; the solids remain in place as the fluid passes through the void space in the material [61]. The fluidized bioreactor is used in wastewater treatment with a sand bed backing up microbial populations and the production of brewing and vinegar [51]. In designing fluidized bioreactors in the reactor, the liquid flows out [57, 59]. Figure 3 shows a fluidized bed bioreactor.

Bubble columns and airlift reactors are also types of fluidized bed reactors; what differentiates between airlift reactors and bubble columns (which are pneumatically agitated) is the type of fluid flow, which depends on the geometry of the system [62]. The two main basic formations of airlift reactors are external loop reactors and internal loop reactors; in the former, the circulation of the fluids follows distinct channels, while there is only a barrier strategically placed in a unique vessel, which creates some channels for the circulation in the later [56]. Airlift reactors are used in biological processes involving some isolated enzymes or residing enzymes within the living cell as solids to produce biopharma proteins etc., from fragile cells [63]. Figure 4 shows a schematic diagram of an airlift bioreactor.

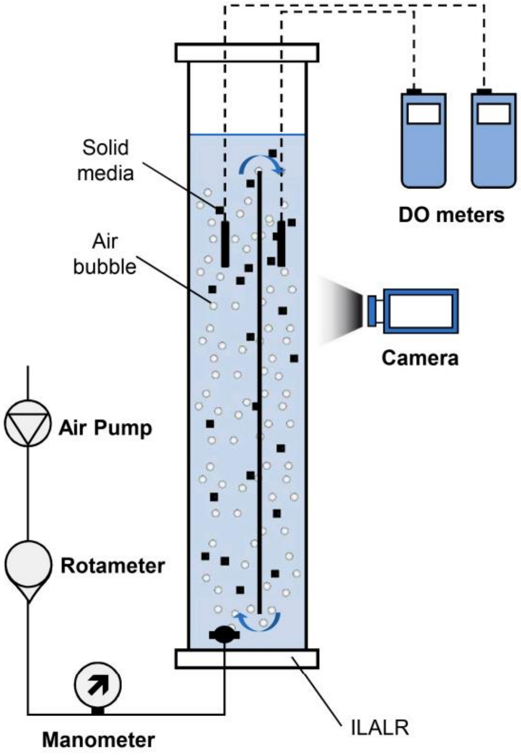

Fig. 4 Internal-loop airlift reactor (ALR) [62]

3.2. Biodigester

Biodigesters have different classifications depending on different parameters, especially the operational parameter, which include: temperature, agitation and retention time; there are three types of digesters: fixed dome, floating drum digester and Balloon [63].

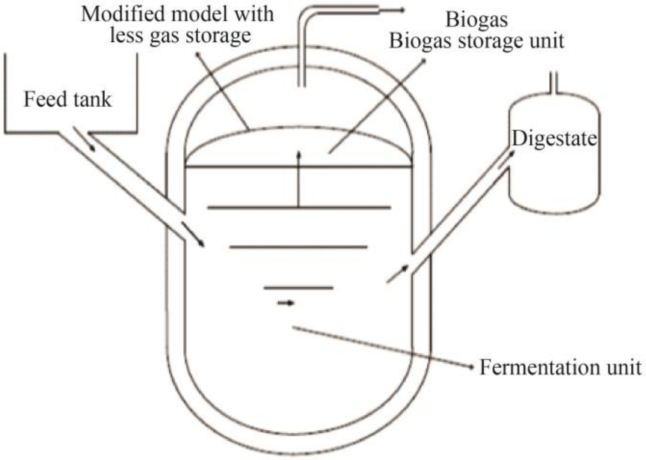

Fig. 5 Schematic diagram of a fixed doom digester [5]

3.2.1. Fixed Dome Digesters

Fixed dome digesters are frequently built underground to keep the digester from temperatures falling at night and during cold seasons [5]. Feedstocks are mixed with water into the mixing tank to make a slurry which is then charged via the fixed dome digester inlet chamber. The digester is only partially filled with slurry, which stays for a longer period of time depending on the retention time for the organic matter to decompose; the organic matter is collected at the outflow tank as digestate (biofertilizer) [52]. The costs of a fixed-dome digester are cheap; it is also simple since there are no existing moving parts and no rusting steel parts, and therefore a lasting period of 20 years or more is expected [64]. Figure 5 shows a schematic diagram of a fixed dome digester.

3.2.2. Floating Drum Digesters

The floating drum bio-digester is multifunctional [51]. It is divided into two portions, with the first portion being fed with the slurry over the inlet to the tank, as shown in Figure 6. The tank has a cylinder-shaped dome that floats on the slurry and collects the gas produced. The slurry is made to undergo degradation (fermentation) for about 50 days, during which the decomposed matter expands and overflows into the next small holding tank [5]. Floating-drum plants are principally used for digesting animals, and humans excrete on a continuous operation feed with daily input. They are often used by small- to middle-sized farms or in institutions and larger agro-industrial estates and are a very simple system to apprehend [66].

3.2.3. Balloon Digester

The balloon digester, otherwise called the plastic bag digester, is the utmost frequently used low-cost plant; it comprises polyvinyl chloride, which constitutes the balloon plant [67]. The gas holder is at the top, and the digester part is below it [51]. Depending on its purpose and method, bio-digesters convert solid waste through a biodegradation process, depending on the nature of the process (anaerobic or aerobic). There are two basic bio-digester based on the design and biodegradation process: anaerobic bioreactor and aerobic bioreactor [68].

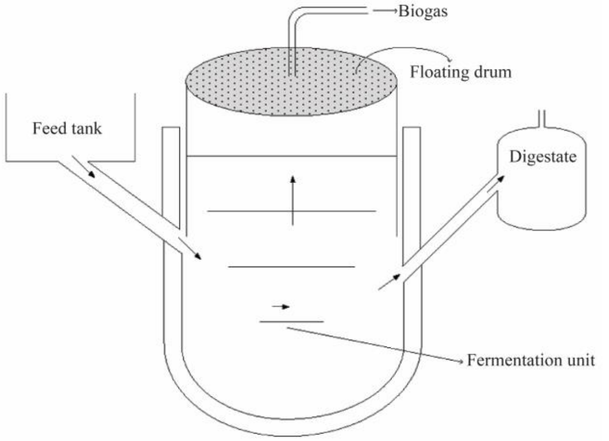

Fig. 6 Schematic view of a floating drum digester [5,67]

3.3. Design of Bioreactor

In an Anaerobic bio-digester, biodegradation occurs without oxygen; an anaerobic bio-digester increases methane generation [7]. Also, [29] reported that the anaerobic process is very intricate, including various groups of microorganisms with numerous environmental necessities. Any alteration in one or more of these operating conditions will affect the growth and performance of bacteria, yield and quality of the biogas and digestate. Also, bio-digester operating temperature, pH, and water are important factors because they are the driving force in the production processes [32]. The anaerobic bioreactor fermentation process is in code possible between 3°C and approximately 70°C, where three temperature ranges of psychrophilic temperature (20°C), mesophilic temperature (20°C and 40°C) and thermophilic temperature (above 40°C) are classified [66]. Keeping the microorganism in an environment suitable for producing the desired product [3].

The anaerobic bioreactor process is likened to what occurs in a cow's stomach, where bacteria in the stomach transform food into a semi-solid material (dung) or fertilizer and biogas (a mixture of methane and carbon dioxide) [8]. Additionally, [65] reported that the anaerobic decomposition of plant or animal material occurs in the presence of anaerobic bacteria, which eat and break down, or digest, biomass and produce biogas and biofertilizer also; the bacterium is naturally present in soils, in water bodies such as wastewater from a treatment plant, lakes and in the digestive tracts of humans and animals.

In designing and fabricating a biodigester, the required component includes a digester tank, inlet for feeding, outlet for the digested slurry, gas collection, and storage system [66]. The yield of microbial biomass and products depends on the strain's genetics and operating conditions [52]. While also in design, it is necessary to consider the characteristics of the place and its capacity and utility [63].

In their study, [2] reported that in bio-digester design, the operating volume (V_d) is centred on the substrates input quantity (S_d) and the selected retention time (RT). Therefore, Equation 2 gives the operating volume.

$$V_D = S_d \times RT\ (m^3) \tag{2}$$

The volumetric capacity of the digester is given as [55]:

$$V_d = \pi r^2 h \tag{3}$$

The retention (RT) is the time taken for biomass to decompose. The retention time for a psychrophilic temperature ranges from 40 to 50 days, the mesophilic temperature ranges between 20 to 40 days, and the thermophilic temperature ranges between 12 to 4 days [67]. The substrate input S_d is given as:

Table 4. Summary of the design configuration in the literature

Parameter	[55]	[2]
Digester volume	4.0 m^3	0.023(m^3)
Gasholder volume	1.0 m^3	
The volume of the gas collecting chamber	0.21 m^3	
The volume of the fermentation chamber	2.36 m^3	0.018 (m^3)
Height of the digester	1.63 m^3	0.0432m
Height of gas collecting chamber	0.3 m	
Height of fermentation chamber	1.33 m	
Height of slurry in the digester	1.90 m	
Diameter of cylinder	1.5 m	0.288m

$$S_d = \text{biomass (B)} + \text{water (W)} = (m^3/\text{ day}) \qquad (4)$$

The total volume of the bioreactor needs to be greater than the operating volume owing to the expansion of the slurry during fermentation, while the operating volume should not exceed 90% [5]. Equation 5 shows the total volume of a bio-digester.

$$V_T = \frac{V_d}{90} \quad (m^3) \qquad (5)$$

Furthermore, Equation 4 shows the geometric formula used to determine the height of the pressure vessel [66].

$$V = \pi r^2 h + \frac{3}{4}\pi r^3 \qquad (6)$$

When designed, conventional bioreactors usually encounter problems; they hardly give room for other adjustments that might be motivated from the end user's viewpoint [3]. Table 4 shows a summary of the design configuration in the literature.

In heat and mass transfer, the mechanism in which heat is transferred in bioreactors can either be by conduction, convection or radiation, subject to the state of matter and contacting pattern in the bioreactor [68]. In heat transfer by conduction, the heat transfer rate is subject to the medium's geometry, thickness, and material and the corresponding temperature difference. Equation 7 describes the process of heat transfer [60].

$$q_x / A = \frac{-Kdt}{dx} \qquad (7)$$

While for mass transfer, [3] reported that there are two factors of worry when dealing with mass transfer in bioreactors, Equation 8 describes the two factors which can be related mathematically:

$$J_A = N_{a/a} = -D_{AB}\, dC_A / d_y + C_A\, U_O \qquad (8)$$

Where J_A is the mass flux of component A, and N_A is the mass transfer rate of component A. A is the cross-sectional area at right angles to the direction of the transfer of component A, D_{AB} is the diffusivity of component A in a mixture of A and B, C_A is the concentration of A, and U_O is the average volumetric velocity of flow of the bulk media. [69]. the most critical thing that determines the success or failure of the biological process is the mass transfer step from the gas to the liquid [68]. The mass transfer rate for this step can be calculated using Equation 9.

$$\frac{dc}{dt} = K_L\, a\, (C^* - C_O) \qquad (9)$$

where C^* and C, respectively, is the solubility of gas and gas concentration in liquid, K_L, the liquid side mass transfer coefficient, and a, the interfacial area.

3.3.1. Agitation and Mixing

Mixing aims to achieve uniformity in temperature, pH, nutrient, substrate and product concentration, and other bulk fluid flow properties of the fermentation media, including viscosity, inside the bioreactor [68]. Mingling in liquid media can be done by agitation with the help of a stirrer, depending on the viscosity of the liquid and if the medium is single- or multi-phased [60]. Also, [36] reported that it is vital to stir the material to attain the appropriate distribution of digestion. This also provides homogeneity of bacteria and temperature and increases the link between the bacteria. Stirring also brings out gas bubbles, thereby preventing settling and layer development. Mixing time is defined as the time (α_M) needed to achieve a required degree of mixing (uniformity) inside a bioreactor [68]. Equation 10 can calculate the mixing time required in a bioreactor.

$$\alpha_M = \frac{C - C0}{C\infty - C0} \qquad (10)$$

4. Kinetics Model

Earlier, [3] reported that an unstructured model can be used to examine microbial growth, substrate ingestion and the product formation rate using Equation 19.

$$\frac{dx}{dt} = \mu X \qquad (11)$$

Where X is the dry weight of cells in (gL^{-1}), t is time (h), and μ is the specific growth rate (h^{-1}). The specific growth rate can be defined in terms of the Monod kinetic model:

$$\mu = \mu m \frac{S}{S + Ks} \qquad (12)$$

Where μm is the maximum specific growth rate (h^{-1}), S is the substrate concentration (gL^{-1}), and K_S is the saturation constant (gL^{-1}). Under non-limiting conditions, combining Equations 12 and 13 gives the combined microbial growth rate equation.

$$\frac{dx}{dt} = \mu X = \mu m \frac{S}{S + Ks} \qquad (13)$$

Table 5. kinetic study of the various model

Reference	Bioreactor	Feedstock	Kinetic Model	Outcome
[70]	Aerobic Batch bioreactor	sawdust, vegetable waste, and sewage sludge	Xi et al. model $\mu = \mu_{max} \frac{S}{K_S X+S}$	Experimental data and the expected values had a very good connection as defined by Xi et al. model
[71]	Anaerobic batch bioreactor	Beverages wastewater treatment sludge	Monod model $\mu = \mu m \frac{S}{S+K_S}$	It has been discovered that the degradation of organic matter was reliant on the growth of the microbes.
[72]	Anaerobic batch bioreactor	Xanthan Gum	Korsmeyer–Peppas model $\frac{Mt}{Ma} = Kt^n$	Release exponents were found in the range of 0.8–0.9, signifying the non-Fickian model of diffusion.
[73]	Aerobic batch reactor	Food waste	First-order kinetic models $r A = k[C / N]^n$	first-order kinetic models defined the microbial mineralization of carbon to nitrogen (C/N).

5. Conclusion

1. The bioreactor design for biofertilizer production requires the knowledge of types of existing bioreactors, design specifications, operating conditions, feedstocks of utilization and microbial activities.
2. Based on the design, bioreactors are classified as anaerobic bioreactors or aerobic bioreactors, while conventional bioreactors are batch bioreactors, continuously stirred tank bubble bioreactors and airlift bioreactors.
3. In bio-fertilizer production, temperature, pH, and other physical and chemical properties are very important in the production processes. Furthermore, the study depicts that different solid waste bio-fertilisers have high efficacy, firmness, cost-effectiveness, simplicity in application, and multi-functionality.

Recommendations

1. More research needs to be done on the potential of replacing chemical fertilizer with biofertilizer if appropriate rationing of feedstock for biofertilizer production is done to produce the right proportion of NPK desired.
2. In the model equation on the possible NPK ratio, a selected substrate should be looked into to give sufficient information on the amount of feedstock to use based on their NPK content. This model should prompt the industrial production of biofertilizers.
3. Additional studies need to be done on the potential of groundnut shells, which have been less explored in the production of biofertilizers.

Acknowledgments

We extend our sincere thanks to the University of Maiduguri.

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